

Driving High-Level Loads With Optocouplers Appnote 4

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Frequently a load to be driven by an optocoupler requires more current, voltage, or both, than an optocoupler can provide at its output.

Available optocoupler output current, of course, is limited by the light-emitting LED section current by the "CTR" current transfer ratio. For most cases, the minimum specified value would be used. The minimum CTR of the IL1 is 20%. Temperature derating is not usually necessary over the 0 to +85 degree Celsius range because the LED light output and transistor beta have approximately compensating coefficients.

Multiplying the minimum CTR by 0.9 would ensure a safe design over this temperature range. Over a wide range, more margin would be required.

The LED source current is limited by its rated power dissipation. Table I shows maximum allowable I_F vs maximum ambient temperature.

Values for Table I are based on a 1.33 mW, 0.6 watt from $t = 100$ mW at 25°C power rating.

Table I

MAXIMUM TEMPERATURE	I_F MAXIMUM
40°C	65 mA
60°C	45 mA
80°C	25 mA

Obviously, one can increase the available output current by either choosing a higher CTR-rated optocoupler, by providing more current, or both. Table II shows the

Table II

P/N	$I_{CE(ON)}$ mA
IL1	9.6

A "buffer-gate," such as the SN7400 provides a very good alternative to discrete transistor drivers. Figure 2 shows how this is done. Note that the gate is used in the "current-sinking" rather than the "current-sourcing" mode. In other words, conventional current flows into the buffer-gate to turn on the LED. This makes use of the fact that the LED current sink is much higher than the source. The SN7400 specifies a current sink of 1.6 mA, loads or 48 mA. Choosing R_F from 75 to 68 ohms adjusts for the higher saturation voltage of the monolithic device.

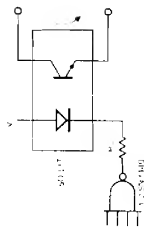


Figure 2: Buffer Gate Drive

MORE CURRENT

For load currents greater than 8.6 mA, a current amplifier is required. Figures 3A and 3B show two simple one transistor current amplifier circuits.

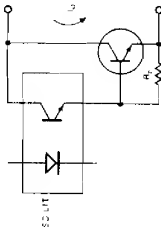


Figure 3A: NPN Current Booster

Since the transistor in the optocoupler is treated as a two-terminal device, no operational difference exists between the NPN and the PNP circuits. R_F provides a return path for I_{CEO} of the output transistor. Its value is: $R_F = 400 \text{ mV}/I_{CEO} (T)$ where $I_{CEO} (T)$ is found for the highest junction temperature expected.

Assume that leakage currents double every ten degrees. Use the maximum dissipated power, the specified maximum junction to ambient thermal resistance,

and the maximum 50-ohm ambient temperature in conjunction with the specified maximum 25 degree Celsius to calculate $I_{CEO} (T)$.

As an example, suppose a 2N3568 is used to provide a 100 mA load current. Also assume a maximum steady-state transistor power dissipation of 100 mW. The junction temperature is 80°C. The thermal resistance to ambient thermal resistance is 333°C/watt, so a maximum junction temperature of 60 + 33 or 93°C is expected. This is about 7 decades above 25°C. Therefore, $I_{CEO} (T) = I_{CEO} (max) \times 2^7 = 50 \text{ mA} \times 128 = 6.4 \text{ mA}$. A safe value for R_F is $400 \text{ mV}/6.4 \text{ mA} = 62.5 \text{ ohms}$.

Working backwards, maximum base current under load will be $I_F/I_{BE(min)} = 100 \text{ mA}/100 = 1 \text{ mA}$. Current in R_B is $V_{BE}/R_B = 600 \text{ mV}/60k = 10 \mu\text{A}$, which is negligible. An IL1 with 9 mA drive would operate effectively.

If the load requires more current than can be obtained with the highest beta transistor available, then more than one transistor must be used in cascade. For example, suppose 3 amperes load current and 10 watt dissipation are needed. A Motorola MJE3055 might be used for the output transistor, driven by a MJE205 as shown in Figure 4. Using a 57-watt heat sink and the rated MJE3055 junction-to-case thermal resistance of 1.4°C/watt, we find that junction temperature rise is 6.4×10 , or 64°. Therefore maximum junction temperature is 124°C. This is 10 decades above 25°C making $I_{CEO} (T) = 2 \times 10^{10} I_{CEO} (max) = 10^{10} I_{CEO} (max)$.

$I_{CEO} (max)$ at 30 volts or less is not given, but $I_{CEO} (T)$ (for safety) a value of 20 for the minimum load current I_F of the device, I_{CEO} could be as large as

the transistors cost less. Of course, performance characteristics of the NPN and PNP versions are identical if the device parameters are also the same.

APPLICATIONS

Optocoupler isolated circuits are useful wherever ground loop problems exist in systems, or where dc voltage level translations are needed. In many systems so-called interrelays are used between a logic circuit section (which may be a mini-computer) and the devices being controlled. Sometimes two levels of interrelays are used in cascade either because of the load power level or because of extreme difficulties with EMI. Optocouplers added by booster circuits such as those described, can replace many of the relays in these systems.

The reed relays, typically used as the first level of interpose and mounted on the interface logic cards in the electronic part of the system, are almost always replaceable by optocouplers since their load is just the coil of a reed relay. This relay may have a coil power of 1/2 to 3 watts and operate on 12, 24 or 48 volts dc.

Assuming worst case design techniques are carefully followed, system reliability should improve in proportion to the number of relays replaced.

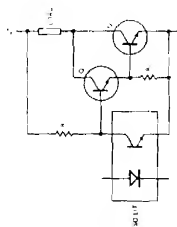


Figure 5A. NPN Darlington HV Booster

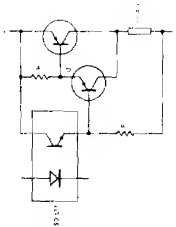


Figure 5B. PNP Darlington HV Booster

If more than one load is being driven and their negative terminals must tie in common, use the PNP circuit, Figure 5B. Otherwise, the NPN is better because

OFF, allows R_2 current to flow into the base of Q_1 , turning Q_1 ON. When the optocoupler is energized, its phototransistor "shorts out" the R_2 current turning Q_1 OFF.

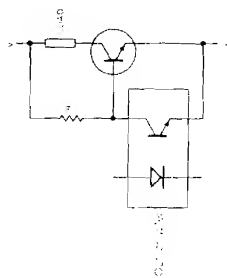


Figure 5A. NPN HV Booster

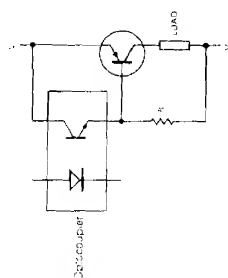


Figure 5B. PNP HV Booster

The value of R_1 depends only on the load supply voltage $V^+ - V^-$, and the maximum required Q_1 base current. This is derived from the minimum beta of Q_1 at minimum temperature and the load current. The required current drive capability is the same as I_{L1} since I_{L1} changes negligibly when the circuit goes between its "ON" and "OFF" states.

In some applications either more current gain will be required than one transistor can provide or the power dissipated in R_1 will be objectionable. In these cases, simply use the Darlington high-voltage booster shown in Figure 6A.

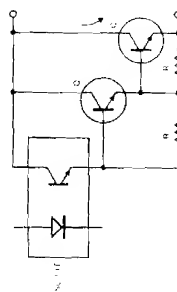


Figure 4. Two-NPN Current Booster

$I_{CQ1} = 20 \mu A$. Then $I_{CQ2}(T) = 35 \text{ mA}$ and $R_2 = 400 \text{ mV}/35 \text{ mA} = 11 \text{ ohms}$. For I_{L1} use $I_{CQ1}(\text{min}) @ 4A1 = 3A/70 = 150 \text{ mA}$. $I_{BQ2} = 600 \text{ mV}/10 \text{ ohms} = 60 \text{ mA}$, so $I_{CQ1} = 210 \text{ mA}$.

Maximum Power in Q_1 will be about 1/4 the power in Q_2 since its current is lower by that ratio and the two collector-to-emitter voltages are nearly the same. This means Q_1 must dissipate 700 mW.

Assuming a small "flag" heat sink having 50 cm^2 thermal resistance, we find the junction at about 95°C. The 150°C case temperature T_{CQO} rating for this device is 2 mA, so one can work backwards and assume about 1.30 of this value, or 70 μA . On the other hand, the 25 μA rated I_{CQO} is 100 μA . Choosing the larger of these contradictory specifications, $R_1 = 400 \text{ mV}/0.1 \text{ mA} = 4 \text{ k}\Omega$. Q_1 base current is $I_{CQ1}/\beta(\text{min}) = 210 \text{ mA}/40 = 5.25 \text{ mA}$. Total collector current $I_{CQ1}(\text{total}) = 2.024 \times 5.25 \text{ mA}$. Table II shows that an $1L1$ could be used here.

MORE LOAD VOLTAGES

All of the current-gain circuits shown so far have one common feature: load voltage is limited by the 30 volt rating of the $1L1$ not by the voltage or power rating of the transistor(s). Figure 5A shows a method of overcoming this limitation. This circuit will stand off BV_{CEO} of Q_1 . The voltage rating of the phototransistor is irrelevant since its maximum collector-emitter voltage is the base-emitter voltage of Q_1 (about 0.7 volts).

Unlike the "Darlington" configurations shown previously, this circuit operates "normally-ON." When no current flows in the LED the phototransistor, being

¹Minimum β_{FE} is obtained using the specification at $I_{CQ} = 2A$ and the "Normalized DC Current Gain" graph given in the Motorola "Semiconductor Data Book," 5th Edition, pp 7-221, 3.